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Westinghouse Savannah River Company engineer Dave Herman chips away at the simulated vitrified high-level waste in a canister at the Savannah River Site's defense waste processing facility (DWPF). This is one of the first canisters ever produced at the DWPF, using nonradioactive materials similar to the actual radwaste to test the canister, which has been cut open for examination.

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Westinghouse Hanford hot-cell technician Ruthlean Hunter handling samples from the U.S. Department of Energy's high-level radioactive waste storage tanks.

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Do you have a comment, a question, glowing words of praise, or maybe a complaint about what you read or don't read in *Radwaste Magazine? Is* there a burning issue on which you'd like to offer your unique and overlooked perspective to the rest of the industry? The **Letters** page of every issue of *Radwaste Magazine* will be an open forum for our readers to air their views and influence the editorial direction of the magazine. We'll print as many letters as space and our better judgment permit, but your best bet is to be clear and concise because your letter may be edited. There's no firm restriction on length, but one and a half double-spaced, typewritten pages should be plenty (diskettes are always appreciated).

PERFORMANCE TEST OF A GAMMA/NEUTRON MAPPER ON TRU WASTE DRUMS

BY ROBERT T. GEHRKE AND NICHOLAS E. JOSTEN

Remediation of radioactive, hazardous, and mixed-waste sites involves unpredictable contact with unknown and potentially dangerous materials. When such materials are encountered, a complex sequence of events that includes waste assay, sorting, treating, and disposing of hazardous and/or radioactive materials is initiated. These follow-on activities strongly impact the speed, cost, and effectiveness of the remediation program.

A "digface" characterization concept was initially proposed at the Idaho National Engineering Laboratory (INEL) in 1992 to minimize the impacts of these follow-on activities while stressing safety and efficiency during remedial field operations. The INEL digface characterization concept promotes unobtrusive, online characterization and monitoring during actual retrieval activities. It is composed of geophysical, radiological, and chemical sensors controlled by an automated (data acquisition and analysis system. The gamma/neutron mapper (GNM) developed for the digface system is designed to rapidly scan gamma-ray and neutron radiation fields during excavation of radioactive waste burial areas.

The primary purpose of the GNM is to provide a spatially accurate quantitative measurement of the gamma-ray and neutron fields during a remediation program in the form of one-, two-, and three-dimensional contour plots. These radiation maps can be used to avoid unanticipated exposure to high radiation fields, to control contamination that could become airborne, to reduce process volume by identifying "clean" areas, to pinpoint specific radioactive objects of interest, and to detect an unintentional nuclear criticality configuration. As with the other sensors, the GNM must be able to perform its scans rapidly so as not to unduly slow the excavation operation. This is done by attaching the GNM to a trolley, gantry crane, or other scanning device so that associated with each acquired radiation field count is an accurate *x*, *y*, and *z* position.

The results reported herein are from a performance test conducted on 55-gallon transuranic waste drums in interim storage at a transuranic storage area building at the INEL radioactive waste management complex (RWMC). This facility is an actual storage facility with stacks of 55 gal waste drums like those that may be encountered at an actual excavation. The only difference between these drums and those buried at an excavation site is that

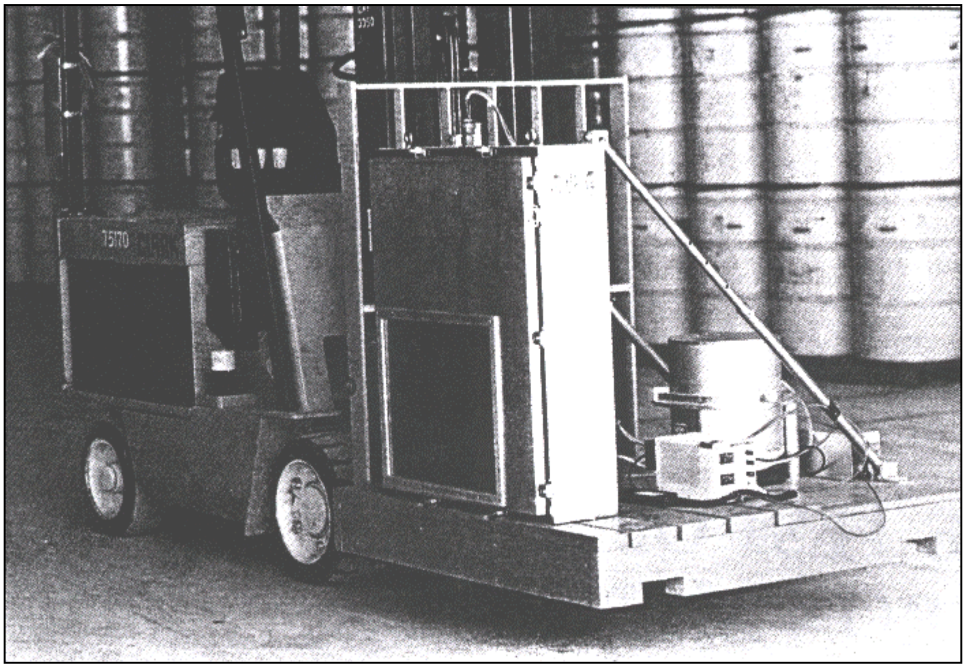

Fig. 1. The gamma-neutron radiation field mapping instrument (GNM), consisting of two plastic scintillation detectors and two ^{3}He detector chambers directly behind the plastic scintillators. This instrument is mounted to a pallet with the acquisition assembly that provides wireless communication with a computer workstation via an RF ethernet.

the drums are neatly stacked, all drums are intact and inventoried, and these drums are not covered with soil. Drums from the Rocky Flats Plant with assorted identification codes were mapped using a forklift to move the GNM.

THE GAMMA/NEUTRON MAPPER

The gamma-neutron mapper consists of two large 25.4 X 48.26 X 3.81 cm plastic scintillators located in front of two helium 3 chambers of the same length and width. The ^{3}He chambers are approximately 10 cm deep (outside dimension). These four detectors are located inside a protective stainless-steel box as shown in figure 1. A 1-mm-thick titanium window is located directly in front of the plastic scintillators to reduce the attenuation of low-energy gamma rays (for example, the 60 keV gamma ray of americium 241). As shown in figure 1, the stainless-steel box with detectors was fastened to a specially built pallet that fits on the tines of a forklift so that scans of vertically stacked 55 gal drums can be made. Also mounted on the pallet are the data acquisition and the sensor interface compartments. These units contain a laser range finder that provides the vertical position of each acquired one-second count and a radio frequency ethernet connection with its antenna.

The computer workstation was located in the rear of a full-size van as shown in figure 2. The van was located near an open door, but the RF antenna for the computer workstation could have been placed inside the building with a cable passing under the door to connect it to the computer. (The RF signal could not penetrate the building's metal walls.) The RF ethernet communication link operates at 2.45 GHz frequency. The workstation consists of a Sun SPARCstation 10 computer, with 32 MB memory, 1 GB disk space, an HP DeskJet 1200C color printer, and floppy disk drive. This system stores all of the data generated by the range finder and the gamma/neutron sensor. A 19 in. color display is driven by a series of pull-down menus and a custom graphical interface written for the X-Windows graphical user interface.

The GNM assembly was maneuvered in the vertical and horizontal directions by an electric forklift with the lift used to vertically scan the stacked drums.

TEST DESCRIPTION

The GNM data were acquired over a 5 X 5 drum matrix (5 stacks of drums with 5 drums per stack) at scan rates of 7.5 cm/s and 15 cm/s. The analog signal was converted to counts per second and stored along with the time and vertical position as measured by the laser range finder. Data were taken at horizontal standoff distances of 15, 30, 45, and 90 cm.

The primary objective of the RWMC test series was to evaluate the GNM in a transuranic waste storage environment similar to the conditions that might be encountered at an actual radioactive remediation site. The specific objectives were as follows: (1) evaluate operation of the GNM under temperature, electrical

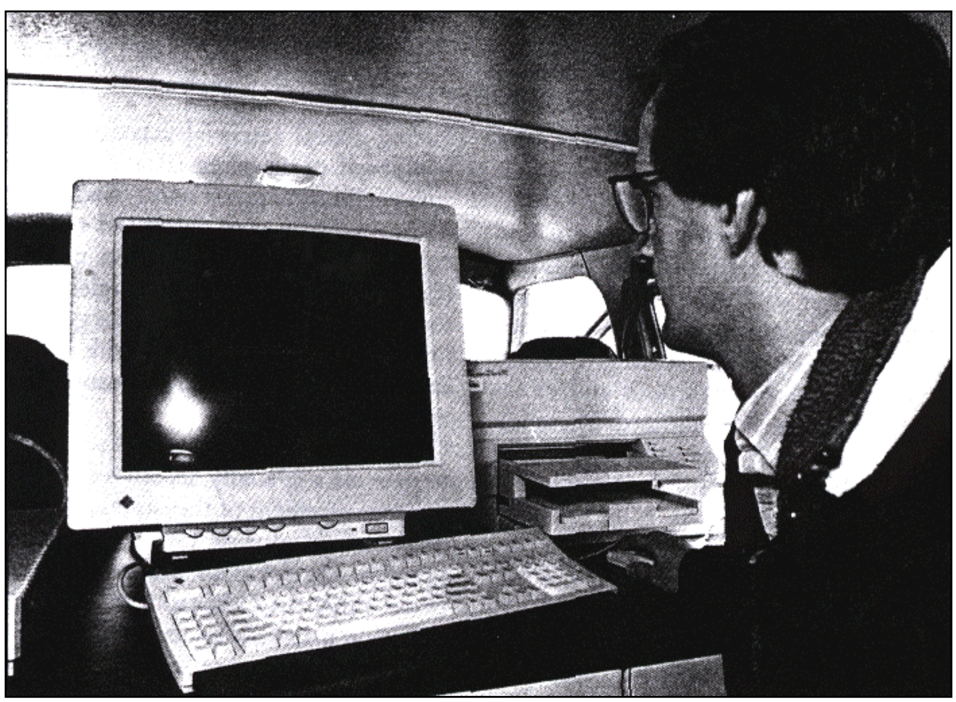

Fig. 2. The Sun SPARC workstation located in the rear cargo compartment of a full-size van. This van was located outside the building containing the waste drums.

Fig. 3. The GNM during a typical scan sequence of the stacked 55-gallon waste drums.

and mechanical noise conditions representative of a field environment; (2) locate hot drums and measure the relative strengths of the radiation fields around the stacked drums and produce color contour maps of the gamma-ray and neutron fields using the acquisition system analysis tools; (3) determine if scan rates of 15 cm/s provided acceptable data for contour plots; (4) evaluate the effect of standoff distance on spatial resolution of the plots; (5) estimate the sensitivity of the GNM for the detection of gamma-ray emitters such as ^{241}Am and, if possible, estimate the neutron sensitivity of the plastic scintillation detectors; (6) compare measurements with drum manifest and SWEPP measurements for selected drums. Figure 3 shows a picture of the GNM, data acquisition system, pallet, and forklift truck during a scan of a typical stack of drums.

Experimental

Prior to the test the GNM was calibrated for gamma-ray and neutron efficiency for "point" source geometry. The gamma-ray scintillation efficiency for each detector at a distance of 30 cm (1 ft) was measured to be about 2 percent for cesium 137. The thermal neutron efficiency of each ^{3}He detector was measured at a distance of 30 cm to be about 0.23 percent for a bare californium 252 source. The GNM was also checked to verify that the lower-level discriminators on the plastic scintillation detectors were set above the noise but below the 60 keV gamma rays emitted by ^{241}Am. The titanium window allows 70 percent transmission of 60 keV gamma rays.

Although a forklift would likely not be the method of choice for moving the GNM during an actual excavation due to the difficulty it has in controlling the scan speed, it was available and expedient to use for this performance test.

As at most excavation sites, the building used for these tests was not heated and inside temperatures lagged outside temperatures by about 5°C. On the day of the test the outside temperature reached a high of about 10°C.

The centers of the two scintillation detectors were aligned with the center of the stack of drums. The width of the two scintillation detectors and of the two ^{3}He detectors behind them is 50 cm. This is only 10 cm less than the diameter of a 55 gal drum and provided sufficient overlap of the vertical scans to prevent voids in the mapping.

The raw data from each experiment was collected as one file consisting of the one-second counts. With each count was listed the time, vertical position, two gamma counts (one from each detector), and two neutron counts (one from each detector). The stack that was being scanned was recorded in the log book since there was no laser distance measurement of the horizontal position. The position of each gamma and neutron count was adjusted to correspond to the center of the detector by aligning it with the center of the highest drum. A grid of the cross sectional projection of the 55 gal drums was overlayed onto the two-dimensional radiation map to simplify interpretation of the data. The contour lines were then added to connect data of equal count rates.

Test Results

The GNM operated flawlessly during the measurements. The temperature inside the building (7.2°C) did not appear to adversely impact any measurements. The forklift operators were able to repeatedly and uniformly scan the stacked drums at speeds of 7.5 and 15 cm/s. At 15 cm/s a full scan of 5 stacks of drums stacked 5 high took about 6 minutes, excluding the time to move the forklift to the next stack and raise the pallet to the top of the vertical position. The RF ethernet transmission link between the sensor interface compartment of the pallet assembly and the workstation worked faithfully.

The averaged gamma-ray count rates with the GNM aligned with the center of each drum are shown in table 1 as item b. The count rate limitation of the plastic scintillation circuitry was exceeded when the GNM scanned drum number 21 (the drum on the top of the third stack from the right). It is estimated that the count rate at this drum exceeded $5X10^{6}$ counts/sec.

Table 1 also shows the measured count rate for the neutron radiation fields along with the health physicist-measured gamma radiation fields and the manifest values for fissile material. The GNM data on the 25 drums was acquired in 6 minutes while the data taken by the HP with his handheld gamma probe took about 20 minutes. The GNM and HP measured radiation fields are in relative agreement. However, in several cases the assay results from the generator manifest do not appear to correlate very well with either the gamma or neutron measurements. Although the manifest values could be correct, it is also possible that waste drums with high gamma or neutron radiation fields (above 300,000 c/s or 150 c/s, respectively, for a standoff distance

Table 1.
Outline of the 25-drum matrix

Drum 6	Drum 11	Drum 16	Drum 21	Drum 26
(a) 1	(a) 1	(a) 9	(a) 35	(a) 1.5
(b) 31,140	(b) 98,900	(b) 600,000	(b) 600,000	(b) 390,600
(c) 49	(c) 82	(c) 108	(c) 146	(c) 102
(d) 1.2	(d) 17	(d) 16	(d) 0	(d) 9.5
(e) 7	(e) 7	(e) 1	(e) 1	(e) 7
Drum 7	Drum 12	Drum 17	Drum 22	Drum 27
(a) 7	(a) 1	(a) 1	(a) 1	(a) 0.5
(b) 612,000	(b) 215,630	(b) 119,050	(b) 72,160	(b) 86,690
(c) 114	(c) 132	(c) 142	(c) 142	(c) 110
(d) 0	(d) 3.2	(d) not available	(d) 1.00	(d) 6.6
(e) 1	(e) 480	(e) 300	(e) 292	(e) 440
Drum 8	Drum 13	Drum 18	Drum 23	Drum 28
(a) 1	(a) 0.5	(a) 0.5	(a) 0.7	(a) 0.5
(b) 119,290	(b) 50,550	(b) 59,830	(b) 55,560	(b) 44,320
(c) 126	(c) 148	(c) 182	(c) 122	(c) 105
(d) not available	(d) 1.4	(d) 32.9	(d) 5.0	(d) 1.4
(e) 337	(e) 7	(e) 480	(e) 1	(e) 7
Drum 9	Drum 14	Drum 19	Drum 24	Drum 29
(a) 6	(a) 0.5	(a) 0.5	(a) 0.5	(a) 1.5
(b) 411,110	(b) 131,870	(b) 64,100	(b) 55,070	(b) 99,630
(c) 172	(c) 134	(c) 134	(c) 176	(c) 164
(d) 117	(d) 2.0	(d) 0	(d) 1.0	(d) 24.8
(e) 1	(e) 4	(e) 7	(e) 334	(e) 300
Drum 10	Drum 15	Drum 20	Drum 25	Drum 30
(a) 1.5	(a) 7	(a) 0.5	(a) 0.5	(a) 4
(b) 151,040	(b) 471,430	(b) 126,620	(b) 39,680	(b) 204,760
(c) 95	(c) 105	(c) 92	(c) 174	(c) 310
(d) 0.66	(d) 7.5	(d) 1.1	(d) 0	(d) 0.13
(e) 1	(e) 1	(e) 7	(e) 7	(e) 320

a. HP γ-ray field measurement with telescoping probe. Measurement is of highest observed radiation field in mr/h.

b. GNM-measured γ-ray field from experiment 1 taken at center of drum. Units in counts/s. Value is the average of two detectors.

c. GNM-measured neutron field from experiment 1 taken at center of drum. Units in counts/s. Value is the average of two detectors.

d. Mass of fissile plutonium material from passive assay with a passive/active neutron assay (PAN) system.

e. Content code: 1-4,7,292 = sludge; 300 = graphite molds; 320 = primarily tantalium crucibles; 330-335 = combustible waste; 337 = plastic and nonleaded rubber; 440 = glass; 480 = metals (including Fe, Al, Cu. and stainless steel). For further information, see T. L. Clements, DOE Report WM-F1-82-021 (Oct. 1982).

of 15.2 cm) and low TRU manifest values were not correctly assayed by the waste generator The use of the GNM to rapidly locate waste drums whose generator-provided fissile content values don't correlate with passive measurements may be an alternate use for the GNM.

Figures 4 and 5 show typical contour plots at standoff distances of 15 cm of the gamma-ray and neutron fields with an outline of the physical dimensions of the drums superimposed over the plot. As shown in table 1, the hot drums identified in the contour plots of the scintillation data correspond, in most cases, to the hot drums identified by the HP with a telescoping probe. Further, little cross interference of radiation from drums appears to have occurred at the 15 cm standoff distance. Since there appears to be little interference of radiation between adjacent exposed drums, it is plausible that there is negligible interference from the drums stored behind these exposed drums.

A comparison of figures 4 and 5 show that not all drums that had high gamma radiation fields had high neutron radiation fields, and vice versa. The differences in the locations of the peak intensities from the gamma and the neutron scan data may result from several possible source-matrix scenarios: (1) the waste matrix contains a combination of neutron moderators and high-cross-section materials to prevent the neutrons from escaping the drum; (2) the waste matrix contains high-atomic-number material to prevent the gamma rays from escaping the drum; (3) the waste contains gamma-ray emitters but no spontaneously fissioning material; (4) the waste matrix contains no spontaneously fissioning material but does consist of material of low atomic number and a strong alpha-emitting radionuclide (like ^{241}Am) to yield neutrons from gamma-neutron reactions but relatively few gamma rays. Scenario 4 may explain some apparent discrepancies with a low TRU content given in the generator-provided manifest and a high neutron field. The drum content code can assist in interpreting the gamma-ray and neutron measurements so that the plausibility of the manifest values can be verified or challenged.

SPATIAL RESOLUTION

The spatial resolving power of a radiation detector such as the GNM becomes a crucial issue for mapping applications such as the TRU drum survey. The resolving capability of a sensor may be thought of in terms of its ability to detect and pinpoint a lateral change in the concentration of a radiation emitter at various standoff distances. The ideal sensor would record an abrupt radiation field discontinuity at an abrupt boundary between radioactivity domains, that is, it would be sensitive only to radiation incident from directly in front of it. Such a sensor would be an ideal tool for locating radioactive drums, comparing levels of radioactivity in different drums, and even for pinpointing the position of radioactive substances within a single drum.

In reality, the field of view of a typical radiation sensor (including the GNM) does not lie exclusively beneath the sensor element. Thus the sensor detects a

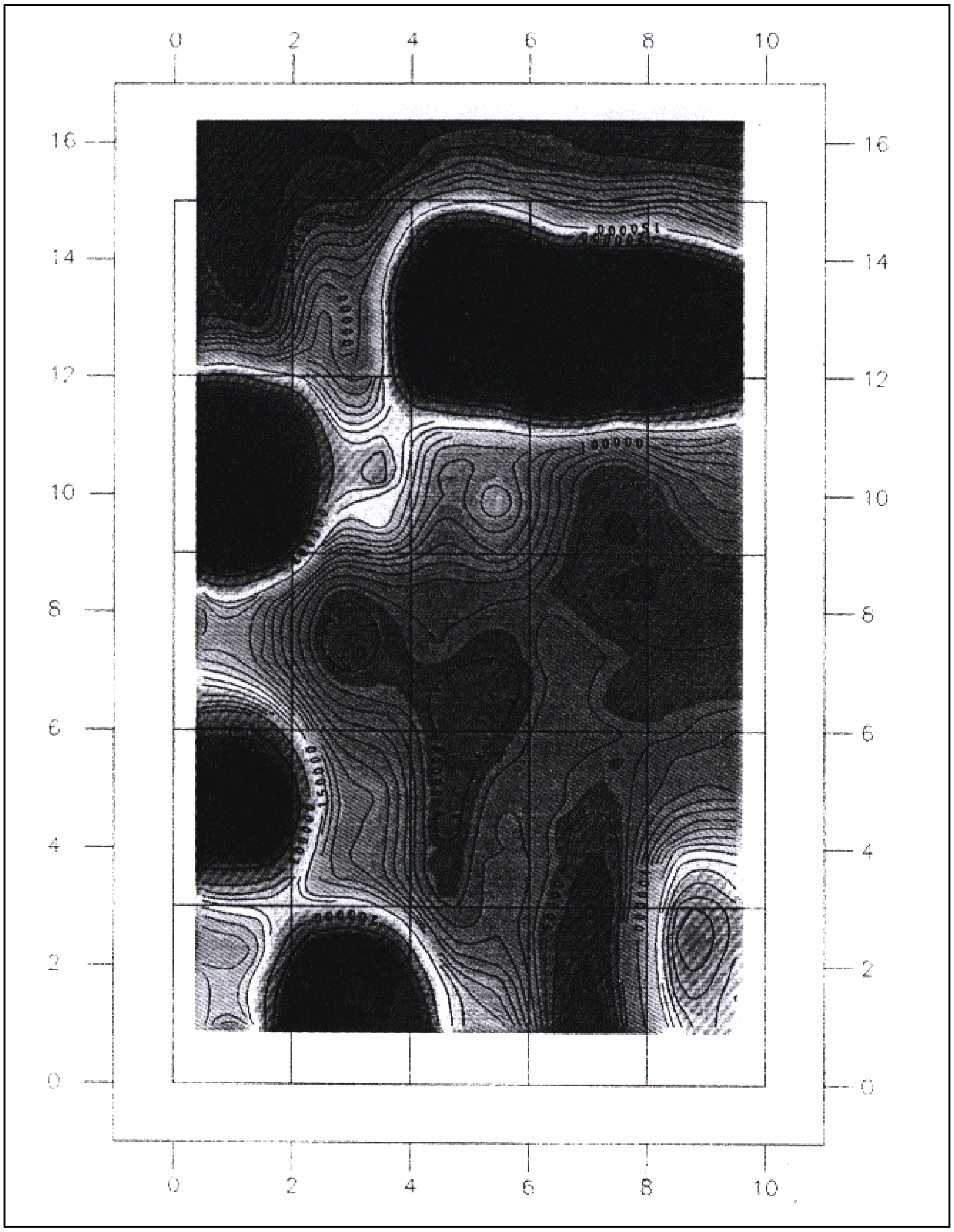

Fig. 4. Contour plot of the gamma-ray count rates acquired at a standoff distance of 15.2 cm and a scan speed of 7.5 cm/s.

lateral discontinuity before it reaches a position directly in front of the discontinuity. The demarcation of sources becomes progressively obscured at the greater standoff distances. Clearly the GNM has a field of view that angles outward from the sensor element on all sides. This causes the measurements to encompass a geometrically increasing surface area of the drum stack as the standoff distance is increased. One of the consequences of this phenomenon is that relative drum radiation intensities appear to change with standoff distance.

Increases in the spatial resolving power of a radiation sensor may be achieved in part through sensor design, for example, by using smaller detector elements or adding side shields. However, these changes involve tradeoffs that effect overall sensitivity and sensor scanning speed. An alternative approach is to focus on analysis methods that account for sensor design and radiation physics. Such methods would improve our ability to derive spatial information from imperfect sensors.

All of the objectives of this performance test were achieved. The equipment performed flawlessly under the temperature, electrical noise, and mechanical noise conditions present during the test, and the personnel effectively carried out the planned measurements. As a result, all experiments were completed in about 6 hours. The temperature of the building did not have any observable effect on the data.

The individual experiments all furnished useful data in a rapid and efficient manner with all 25 drums being scanned in about 6 minutes or less, excluding a short repositioning time for the forklift to move from stack to stack. The radioactively hot drums were easily identified. Although the forklift is not intended to deliver a uniform speed for the purpose of scanning, the forklift operator did an excellent job of obtaining relatively uniform scan speeds.

The sensitivity of the plastic scintillators for the 60 keV ^{241}Am gamma rays was only indirectly demonstrated by the very high count rates encountered, even with those drums emitting lower radiation fields. The radionuclide typically responsible for the gamma radiation fields is ^{241}Am. A 1 mr/h radiation field corresponds roughly 100,000 to 150,000 c/s for each plastic scintillator.

A scanning speed of 15 cm/s resulted in measurements with spatial resolution as good as with a scanning speed of 7.5 cm/s. It takes 3 seconds for the detector

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to pass over a specific position being scanned. Since the collected counts are for a one-second count, some additional increase in scanning speed may be possible without jeopardizing the spatial resolution.

The contour plots were found to be very useful in identifying the locations in the waste drums of the highest levels of radiation.

As observed from table 1, the correlation between the gamma radiation fields measured by the HP and the GNM gamma scans was very high. The correlation between the GNM neutron-radiation scans and the fissile assays reported on the manifest is not as high. In particular, the zero fissile-content values reported for waste drums number 7, 19, 21, and 25 are suspicious, and drum number 21 is particularly so in light of the high neutron-radiation field measured by the GNM. Conversely, the manifest for drum number 11 reports 11 grams of fissile plutonium but the neutron field as measured by the GNM is relatively low. Use of the GNM for rapidly identifying potentially mislabeled waste drums actually containing high levels of fissile material should be considered.

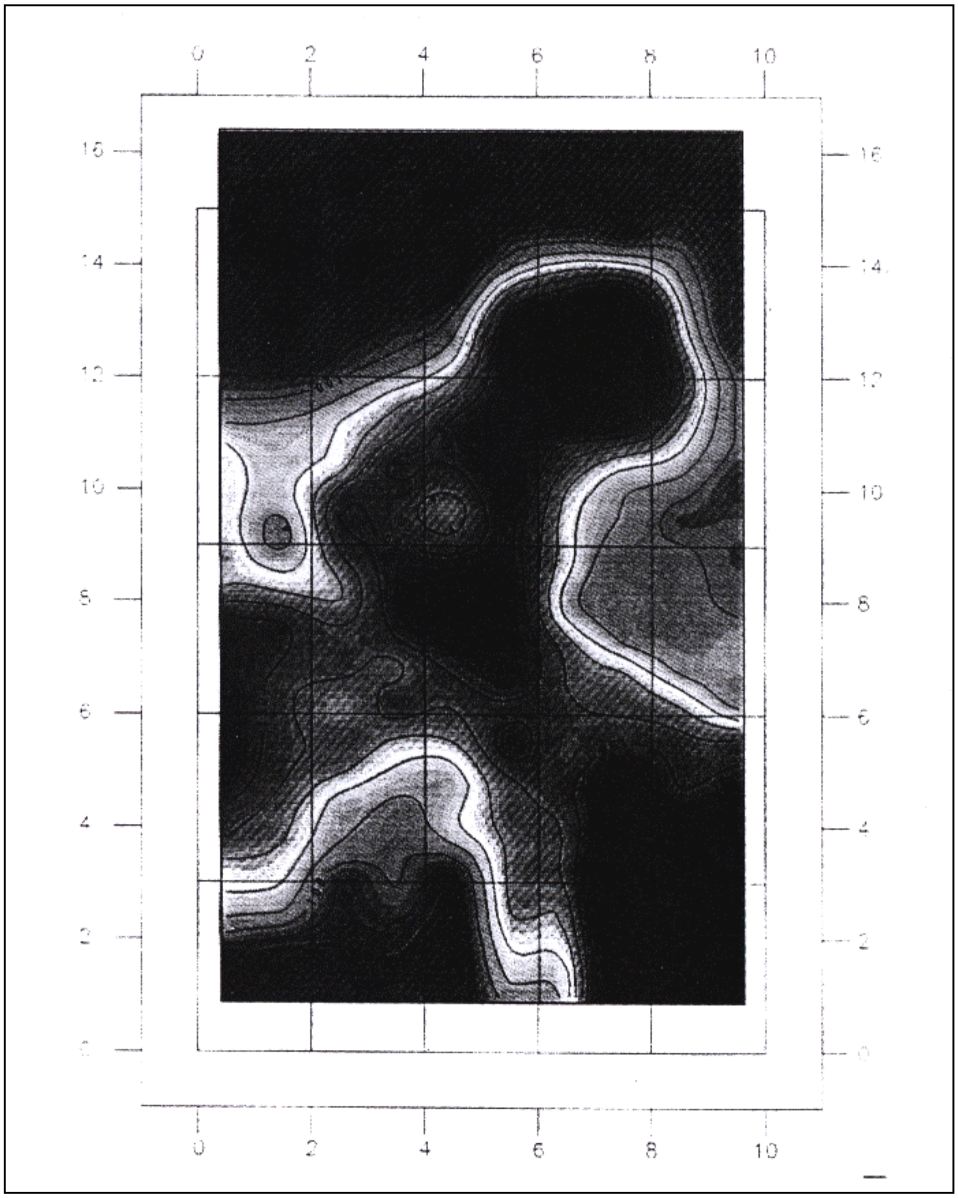

Fig. 5. Contour plot of the neutron count rates acquired at a standoff distance of 15.2 cm and a scan speed of 7.5 cm/s.

Further Reading

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Working at the INEL since 1990, **Nicholas E. Josten** has been active in research on nonintrusive investigation methods for characterizing buried radioactive, hazardous, and explosive waste. He proposed a concept for monitoring hazardous material excavations in 1992 and, with a team of INEL scientists and engineers, has developed this concept toward commercial viability.